DISTINCTIVE FEATURES OF THE DESIGN OF AN ELECTROCHEMICAL IMPEDANCE METER WITH QUADRATURE NOISE COMPENSATION

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UDC 621.317.332.1.08

The block diagram and design are considered for an impedance meter for measuring the impedance components of electrochemical objects with almost equal errors in the frequency range $10^{-10^3}$ Hz for $\tan \delta = 0, 1, \ldots, 10$.

The impedance–frequency relation is characteristic of electrochemical objects (ECOs). The values of the impedance components may differ greatly (tens of times) from each other [1, 2]. In measurements of the impedance using directly proportional transformation of the impedance, the harmonic signal is very difficult to measure with the necessary accuracy of a minor component of the impedance. In that case, the error of measurement is determined primarily by a vector–scalar transducer (VST) because its output forms the signal from the unmeasured component of the harmonic signal, which is a quadrature noise relative to the signal measured in the VST.

Below we consider the distinctive features of the design of a meter for measuring the impedance of an electrochemical object with noise compensation in the channel for measuring the desired impedance component.

The meter is based on the principle we proposed earlier for compensation of quadrature noise in a VST [4]. The block diagram of the meter is shown in Fig. 1. The object of study, an electrochemical cell $EC$, contains auxiliary $AE$, working $WE$, polarizing $PE$, and reference $RE$ electrodes. The diaphragm $D$ eliminates reaction products that form at the polarizing electrode when the constant component of the current flows through the cell, in the main volume of the cell where the working (studied) electrode is located. The required polarization conditions of the working electrode are ensured by the polarization regulator $PR$. For a given working electrode potential the potential difference $E_{\text{w}}$ between electrodes $WE$ and $RE$ are compared to the voltage $E_{\text{sh}}$ of the internal (mounted in $PR$) or external shaper. When the compared quantities are unequal $PR$ sets a polarization current $I_p$, which flows in the circuit $RE-D-WE$. Ignoring the error of static regulation ($\delta E \leq 10^4-10^5$), that current establishes the equality

$$E_{\text{w}}(t) = E_{\text{sh}}(t),$$

where $t$ is the comparison time in the $PR$.

Under the working electrode polarization set by the current the connection between the reference electrode $RE$ and the $PR$ input is broken. Voltage from the standard resistor $R_0$, through which the $WE$ polarization current flows, is applied to the same $PR$ input by means of the internal commutator. Then the equation

$$I_p(t) R_0 = E_{\text{sh}}(t),$$

apart from the static regulation error, is established in the regulation circuit; it follows from that equation that

$$I_p(t) = E_{\text{sh}}(t) R_0^{-1} = K E_{\text{sh}}(t),$$

where $K = R^{-1}_0 = \text{const}$ is the scaling factor of the polarization current.

Translated from Izmeritel'naya Tekhnika, No. 8, pp. 56-59, August, 1998.
Fig. 1. Block diagram of the impedance meter for ECOs with quadrature noise compensation.

Conditions specified by the harmonic component of the current I₀ are formed in the circuit in the meter that contains the series-connected attenuator output A₁, the connecting cable CC, the part of the electrochemical cell EC between the auxiliary and working electrodes (AE and WE) with the impedance Z₀ to be measured, the primary winding of the current transformer CT, and the output of the voltage follower VF. For that purpose the current I₀ is transferred by means of the transformer CT to the current–voltage measuring transducer CVT, which forms the voltage

\[ E_{cv} = -I₀ K₁ K₂, \]  

(1)

where \( K₁ \) and \( K₂ \), respectively, are the transfer coefficients of the CT and CVT.

As follows from Eq. (1), vectors \( E_{cv} \) and \( I₀ \) are antiphase. The voltage \( E_{cv} \) is detected in the control signal shaper CSS, is compared with the level set by the standard \( U₀ \) and the error signal \( E_y \) isolated, is then amplified and sent to the control input of attenuator A₁, changing its output voltage and, therefore, the absolute value \( |I₀| \) of the current. As a result, apart from the static error, the equality

\[ |E_{cv}| = U₀ \]  

(2)

is ensured at the input of the control signal shaper.

Subtracting Eq. (1) from Eq. (2), we have \[ |I₀| = U₀ |K₁ K₂|^{-1}. \] If \( K₁ = K₂ = K \), in the operating frequency range of the meter, then \[ |I₀| = U₀ |K₁ K₂|^{-1} = K = \text{const}. \] Conditions with a given amplitude of the sinusoidal current are formed in the circuit under consideration. Those conditions do not depend on the impedance \( Z₀ \) between the electrodes AE and WE of the electrochemical cell.

In the meter under discussion the direction of the vector \( E_{cv} \) (Fig. 2) is taken for the origin for reckoning the phase angles of the other vectors. The voltage \( E_{cv} \) as a reference, therefore, is applied to the quadrature phase inverter QFI (see Fig. 1) and to the in-phase input of the vector–scalar transducer VST; the voltage \( jE_{cv} \) shifted by 90° enters the quadrature input of the VST.

Flowing through the measured impedance \( Z₀ \), the current \( I₀ \) causes the voltage in it to drop by

\[ E₀ = I₀ Z₀ = K |Z₀| (\cos φ + j \sin φ) = KR + j KX, \]  

(3)

where \( φ = \arctan \left( \frac{|Z₀| \sin φ}{|Z₀| \cos φ} \right) \) is the phase shift between the vectors \( E₀ \) and \( I₀ \) caused by the impedance \( Z₀ \), \( R = |Z₀| \cos φ \) and \( X = |Z₀| \sin φ \) are the real and imaginary components of the \( Z₀ \).

In impedance measurements without compensation for the quadrature noise the commutator Com is put in the 0 position. The input of the attenuator A₂ is connected to the common wire and the primary winding of CT and the output of the follower VF have zero voltage (the secondary winding of the transformer works in a mode close to short circuit because